

Geology of the Cape Porcupine Complex (NTS 11F/11), Guysborough County, Nova Scotia¹

C. E. White, S. M. Barr², J. W. F. Ketchum³ and M. Ethier²

Introduction

Detailed mapping in the Cape Porcupine area of northern mainland Nova Scotia (NTS sheet 11F/11; Fig. 1) was begun in the summer of 2000. This project follows up on regional mapping done by White and Barr (1998a, b) in the Guysborough-Mulgrave-L'Ardoise area, as well as earlier mapping by Fletcher (1881, 1884), Ferguson (1946) and Ferguson and Weeks (1950) in the Strait of Canso area.

Cape Porcupine, a prominent hill adjacent to the Canso Causeway, consists of varied igneous and metamorphic rocks termed the Cape Porcupine Complex by White and Barr (1998a, b). The Cape Porcupine Complex holds a strategic position in the configuration of tectonostratigraphic terranes in the northern Appalachian orogen (Fig. 2). Hence, this study was undertaken to (1) describe the rock types that form Cape Porcupine, (2) determine their age, and (3) compare them to other "basement" rocks in northern mainland Nova Scotia and adjacent parts of Cape Breton Island. This paper provides an overview of the preliminary results of the project and outlines additional work planned to resolve some remaining geological problems.

Map Units

Introduction

Fletcher (1881, 1884) published an extensive description of the geology at Cape Porcupine. He divided the hill into a "central slate series" surrounded by "syenite" and "felsite", unconformably overlain by Devonian sedimentary rocks. The area was remapped by Ferguson (1946) and Ferguson and Weeks (1950). They subdivided the slate series and felsite into an older unit of andesite, chlorite schist, rhyolite and felsite, intruded by younger granite and alaskite, and overlain by Carboniferous sedimentary rocks of the Horton Group.

As a result of quarrying from 1952-55 at Cape Porcupine for the construction of the Canso Causeway, several theses were completed on the area by students from St. Francis Xavier and Dalhousie universities, and the Massachusetts Institute of Technology (e.g. Breau, 1954; Hilton, 1954; Gillis, 1956; Rowley, 1956; Power, 1957). These studies concentrated on drill core descriptions and petrographic analyses but did not significantly change the geological map of Ferguson (1946).

Quarry operations continue at the present time, and provide excellent exposure of the varied igneous and metamorphic rocks of the Cape Porcupine Complex. Rocks of the complex are now in faulted contact on the north, east, and west with conglomerate, sandstone and slate of the Lower Carboniferous Clam Harbour River Formation (Fig. 3). However, the southern margin of the hill appears to preserve an unconformable relationship between the complex and the Clam Harbour River Formation, as indicated by the presence of a basal conglomerate that contains abundant clasts derived from the complex. As a result of our mapping and petrological studies, the Cape Porcupine Complex is divided into five map units (Fig. 3), as described below.

Metasedimentary Unit

The main body of metasedimentary rocks occupies the central area of the Cape Porcupine Complex, and is mainly fault-bounded (Fig. 3). The contact with the western granitoid unit appears to be a brittle thrust fault dipping to the west, with the granitoid rocks thrust over the metasedimentary rocks. On the east, the metasedimentary unit is in contact with metavolcanic and granitoid rocks along a vertical fault. The metasedimentary unit consists mainly of grey to black, fine-grained and strongly foliated metasiltstone with well-developed stretching lineation (see Structure and Metamorphism section). Locally the metasiltstone contains thin (<0.5 mm thick), light grey, fine-grained

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² Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0

³ Royal Ontario Museum, 100 Queens Park, Toronto, Ontario M5S 2C6

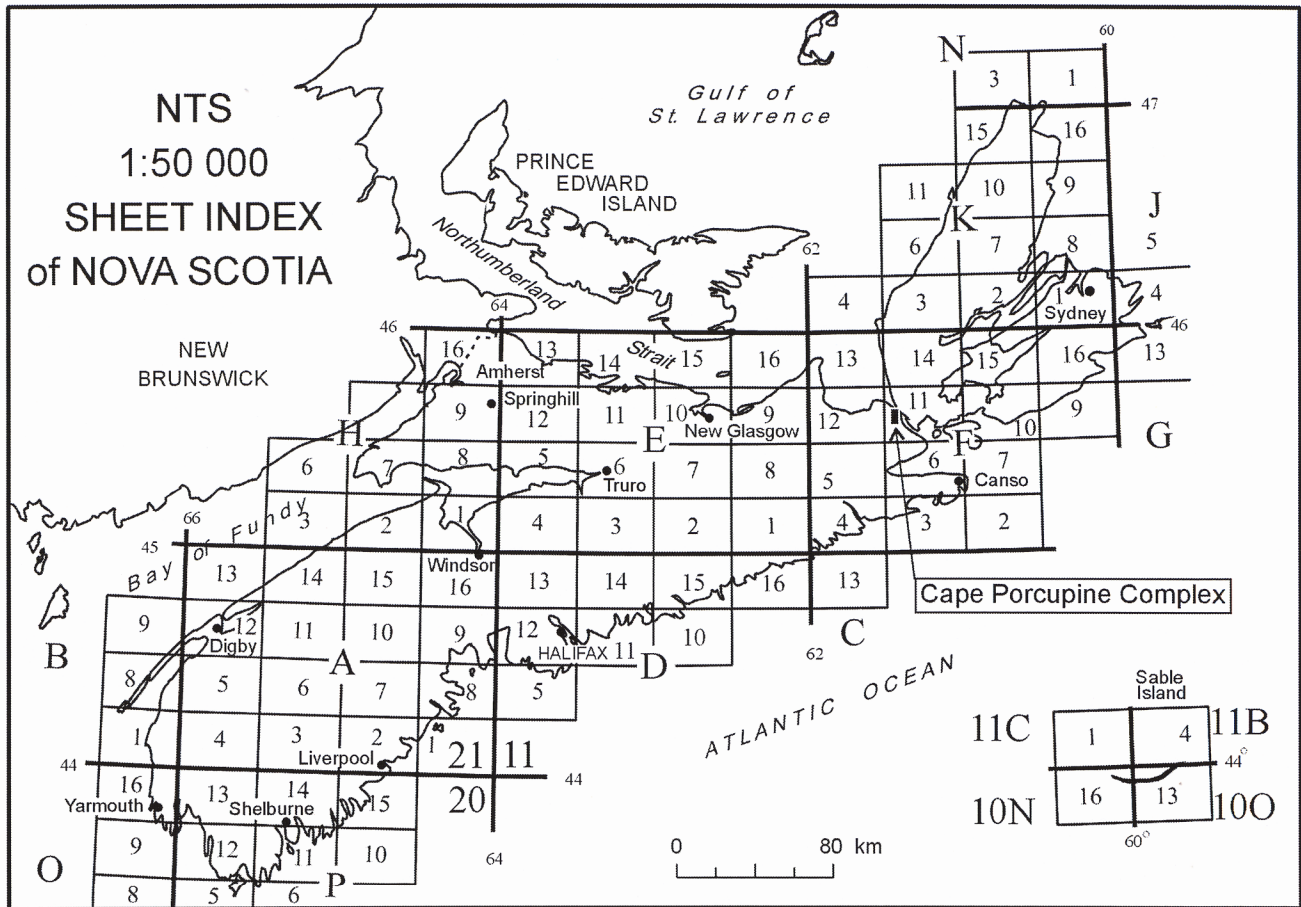


Figure 1. National Topographic System (NTS) index map of Nova Scotia showing location of the Cape Porcupine Complex.

metasandstone lenses. Rare quartzite occurs in laterally discontinuous layers, 1-2 m in thickness, in the metasilstone. The quartzite is light to dark grey, fine-grained, heavily fractured and featureless. Along the western contact with the granitoid rocks the metasilstone locally contains mappable metavolcanic lenses (Fig. 3).

Most of the metasilstone is strongly deformed and recrystallized so that original sedimentary structures have been obliterated. This evidence for mylonitization suggests that the rock is more properly termed a phyllonite. Although this unit has been interpreted to be intruded by granite (e.g. Ferguson, 1946), no evidence for such a relationship, such as contact metamorphism, was observed during the present study.

Metavolcanic Unit

The metavolcanic unit outcrops in the eastern part of the complex and is mainly fault-bounded (Fig. 3). It consists

dominantly of white-weathered, grey to dark grey, crystal to crystal-lithic rhyolitic tuff. Crystals are small (<3 mm maximum diameter) and include rounded embayed quartz, subhedral anorthoclase, and subhedral plagioclase set in a fine-grained to aphanitic, locally spherulitic, groundmass of microcrystalline quartz and feldspar. Lithic clasts are generally small (<1 cm in diameter), flattened parallel to foliation, and typically consist of rhyolitic tuff. Clasts of andesitic tuff and metasilstone are rare. Using the relative modal abundances of crystals, the tuffs range from alkali rhyolite to rhyolite (Fig. 4). As in the metasedimentary unit, the tuff is strongly foliated and the lineation is defined by elongate quartz crystals and lithic clasts. Volcanic layering is difficult to recognize because of the strong foliation and, where present, layering has been transposed parallel to foliation. The original relationship of the metavolcanic unit to the metasedimentary unit is unknown, but based on the presence of rare metasilstone clasts in the metavolcanic rocks and metavolcanic lenses in the metasilstone unit, they may be interlayered.

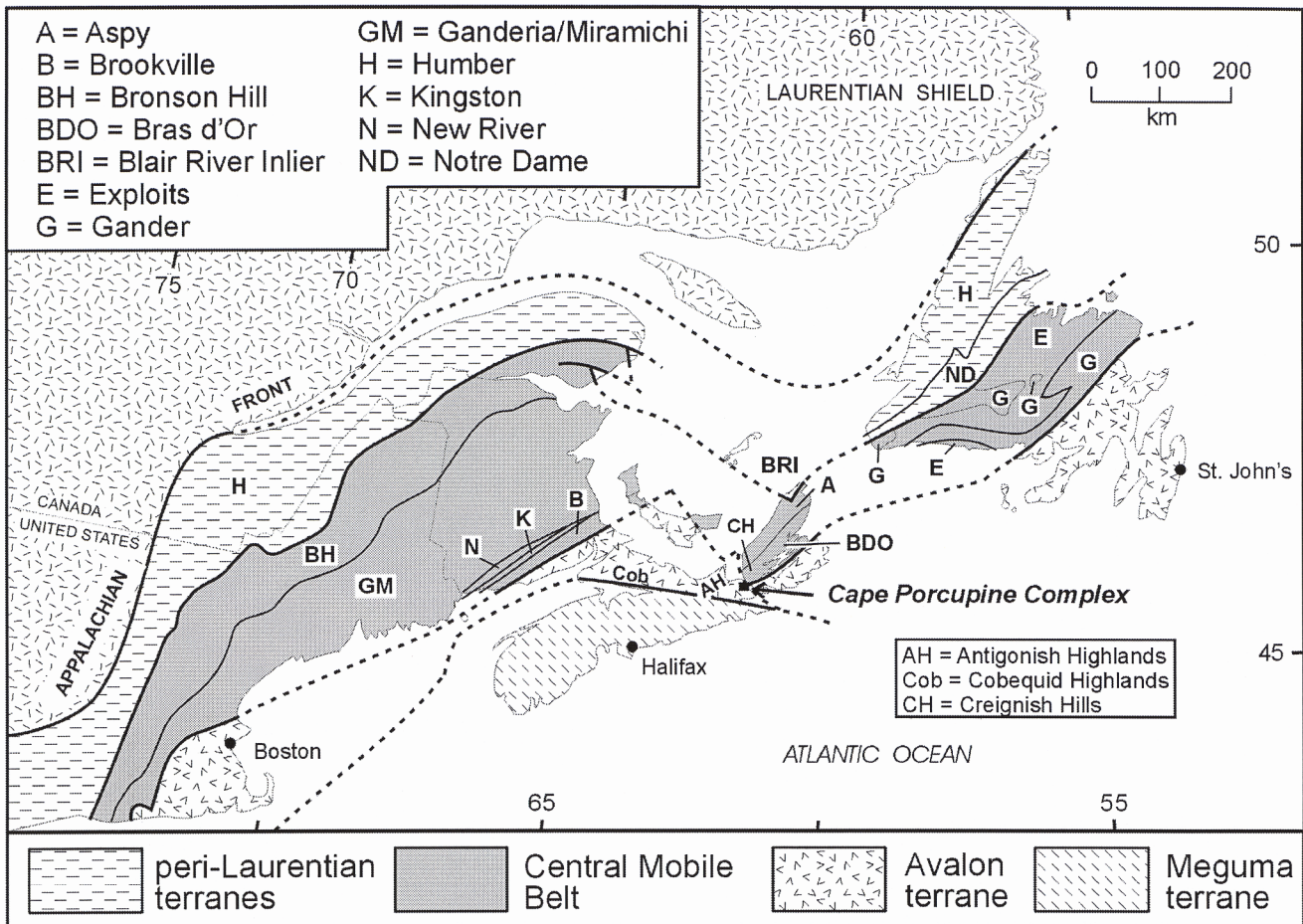


Figure 2. Location of the Cape Porcupine Complex in relation to the tectonostratigraphic subdivisions in the northern Appalachian orogen (modified from Barr *et al.*, 1998).

Granitoid Units

Granitoid rocks form both the western and eastern parts of the Cape Porcupine Complex (Fig. 3). Based on the presence of similar alkali-feldspar granite in both areas, the western and eastern units are inferred to be co-magmatic, although they are everywhere separated by the fault-bounded metasedimentary and metavolcanic units. In both areas, the granitoid rocks display variably cataclastic textures, but mylonitic granite was observed only in the eastern unit.

Western Granitoid Unit

The western granitoid unit consists mainly of pink to pink and grey granite, mixed with abundant enclaves of more mafic plutonic rocks and metavolcanic rocks of andesitic to rhyolitic composition. The granite appears to vary gradationally in composition from monzogranite to syenogranite, and alkali-feldspar granite (Fig. 4). Texture also varies from coarse-grained equigranular to

medium-grained porphyritic with phenocrysts of quartz and plagioclase up to 1 cm in length. Interstitial granophyre generally is present in alkali-feldspar granite and syenogranite samples. Mafic minerals may have originally been hornblende and biotite, but they have been entirely altered to chlorite and iron oxides. Accessory minerals include zircon, titanite, apatite and magnetite.

Plutonic enclaves in the granitic rocks are of leucodiorite/quartz diorite and tonalite composition. The leucodiorite/quartz diorite is white to light grey, medium- to coarse-grained and inequigranular, and consists of a framework of subhedral plagioclase grains and interstitial mafic minerals, locally forming up to 30% of the rock. The mafic minerals include amphibole that has been partially to entirely replaced by chlorite, and possibly clinopyroxene, now entirely replaced by chlorite and iron oxides. Minor interstitial quartz and rare perthitic alkali feldspar are also present. Accessory minerals include abundant euhedral apatite, as well as

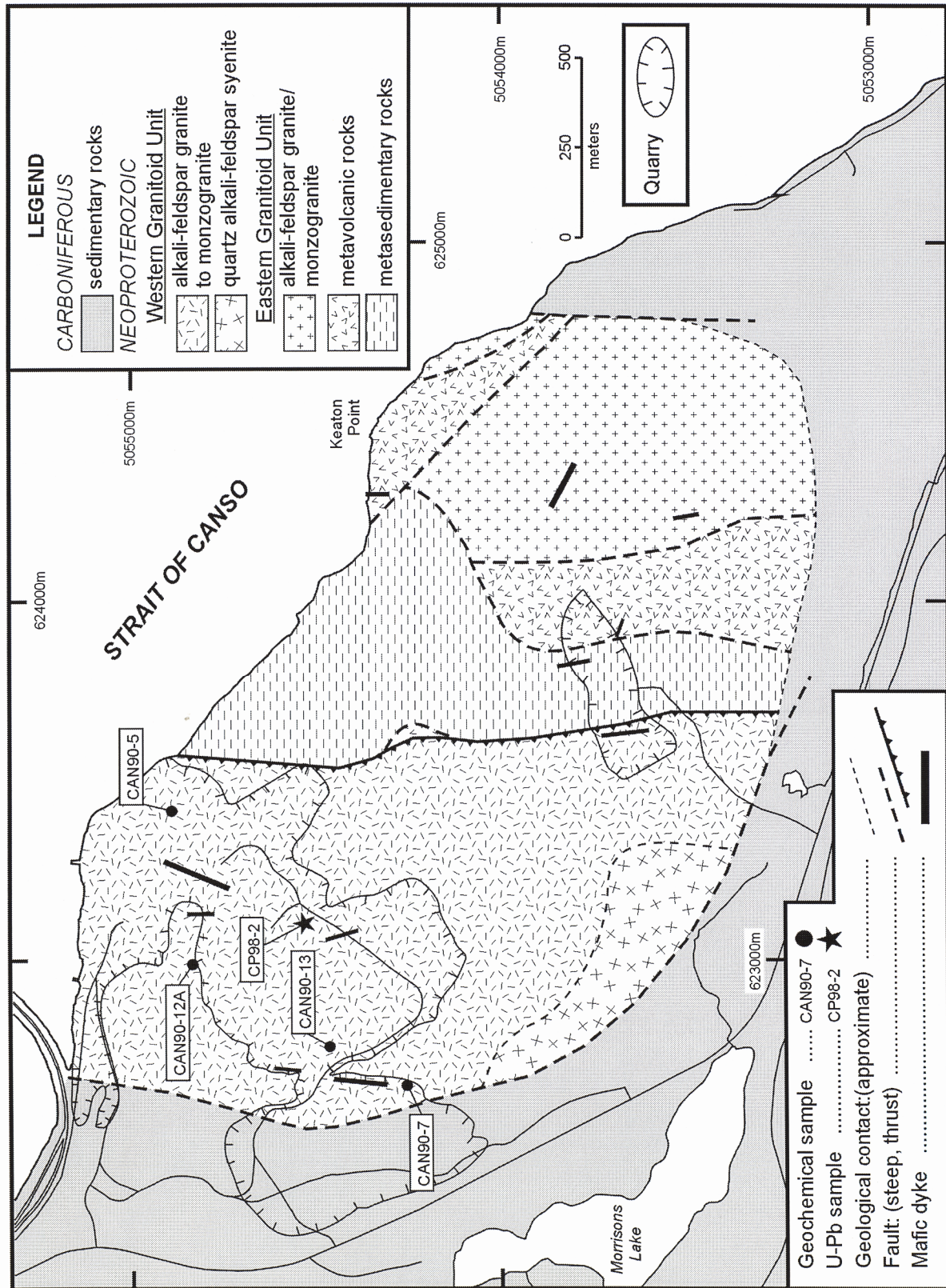


Figure 3. Simplified geological map of the Cape Porcupine Complex.

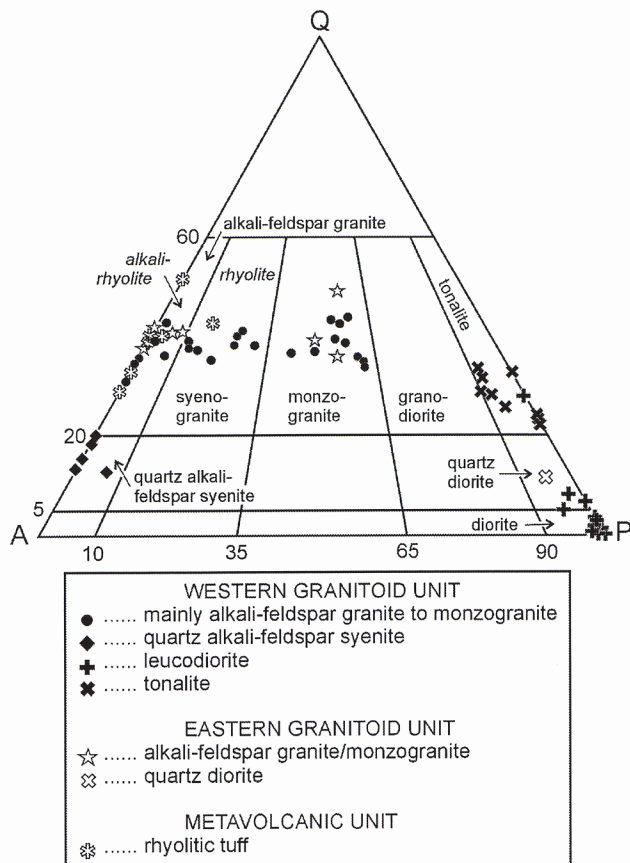


Figure 4. Ternary plot of modal quartz (Q)-plagioclase (P)-alkali feldspar (A) compositions (after Streckeisen, 1976) for samples from the granitoid and metavolcanic units in the Cape Porcupine Complex. Italicized names refer to volcanic equivalents.

zircon, titanite, and magnetite. Tonalitic enclaves in the granitic rocks are dark grey to pinkish-grey, fine- to medium-grained and equigranular, but locally contain phenocrysts of quartz and plagioclase up to 1 cm in length. They consist mainly of plagioclase laths, accompanied by up to 20% chloritized amphibole and clinopyroxene(?). Accessory minerals include apatite, titanite and magnetite.

A mappable body of quartz alkali-feldspar syenite occurs in the southwestern part of the western granitoid belt (Fig. 3). The syenite is typically red to red and grey, medium- to coarse-grained, and composed of euhedral to subhedral, coarsely perthitic alkali feldspar and interstitial quartz. Dark green euhedral amphibole, altered pyroxene(?) and secondary chlorite locally constitute up to 10% of the rock. A distinctive characteristic of this unit is the abundant interstitial magnetite (up to 9%). Titanite and apatite are additional accessory phases. The relationship of syenite to the more granitic rocks of the Cape Porcupine Complex is

not known. However, both granitic and syenitic rocks contain similar perthitic alkali feldspar and tonalitic enclaves and, hence, are inferred to be of similar age.

Eastern Granitoid Unit

The eastern granitoid unit consists mainly of alkali-feldspar granite with local areas of monzogranite and quartz diorite (Fig. 4), similar to compositionally equivalent rocks in the western granitoid unit, and is assumed to be of similar age. However, the alkali-feldspar granite in the eastern granitoid belt is more deformed than in the western belt and in places discrete mylonite zones are present. The mylonitic granite zones appear to correspond to the "gneissoid" beds of Fletcher (1881). In these zones, few of the primary igneous features are preserved, but the rocks appear to have been coarse grained, with abundant quartz and alkali feldspar, and in some cases plagioclase. The mylonite contains abundant quartz ribbons and K-feldspar augen in a fine-grained quartz-feldspar groundmass.

Mafic Dykes

Mafic dykes are a minor component in all units of the Cape Porcupine Complex, as well as in the Clam Harbour River Formation (e.g. White and Barr, 1998a). They are typically 1 to 2 m wide, although the largest observed dyke is about 5 m wide, and are fine- to medium-grained with well developed chilled margins. Many of the dykes are undeformed and cut mylonitic fabrics in the host rocks. Such dykes consist dominantly of intergranular plagioclase, clinopyroxene and opaque minerals. They are likely to be Early Carboniferous in age because they occur in the Clam Harbour River Formation as well as in the older units. However, some mafic dykes in the complex are very altered, contain amphibole and/or chlorite instead of clinopyroxene, and may represent older episodes of dyke emplacement.

Clam Harbour River Formation

The Clam Harbour River Formation was assigned to the lower part of the Carboniferous Horton Group by White and Barr (1998a). In the Cape Porcupine area, the formation consists mainly of light grey to green sandstone and siltstone interlayered with grey polymictic conglomerate and minor black laminated siltstone and shale. Clasts in the conglomerate are dominantly rock types that occur in the Cape Porcupine Complex, indicating that the formation was deposited unconformably on the complex, although most of the present contacts appear to be faults (Fig. 3).

Age

To better constrain the age of the Cape Porcupine Complex, a sample of syenogranite from the western granitoid unit was collected for dating (Fig. 3). The analyzed sample consists of coarse-grained quartz in a matrix of medium-grained alkali feldspar and minor plagioclase. Analytical work was carried out at the Radiogenic Isotope Facility at the Memorial University of Newfoundland following the methods outlined in Ketchum *et al.* (1997).

The sample yielded a single population of colourless, euhedral to subhedral, doubly terminated zircon prisms (length/breadth ratio 2:1), most of which contain minor solid and fluid inclusions and cracks. The best quality grains lack inclusions and cracks but are not abundant. The sample also yielded a small quantity of turbid yellow monazite grains that were not analyzed because of their poor quality. Three abraded zircon fractions (Z1-Z3) plot as slightly discordant clusters (Fig. 5) with $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 609-613 Ma (Table 1). Because the precise age of these fractions is somewhat ambiguous, a fourth fraction of best quality, strongly abraded grains was analyzed. This fraction (Z4) yielded a concordant age of 608 ± 6 Ma. However, in considering the range of all $^{207}\text{Pb}/^{206}\text{Pb}$ ages, the ± 6 million year uncertainty appears to be somewhat high for the sample age. We instead prefer to cite an age of 610 ± 3 Ma for the Cape Porcupine granite, which spans the range of $^{207}\text{Pb}/^{206}\text{Pb}$ ages of all fractions.

Because petrographic features suggest that all of the granitoid rocks in the Cape Porcupine Complex are co-magmatic, it is assumed that the U-Pb age of ca. 610 Ma

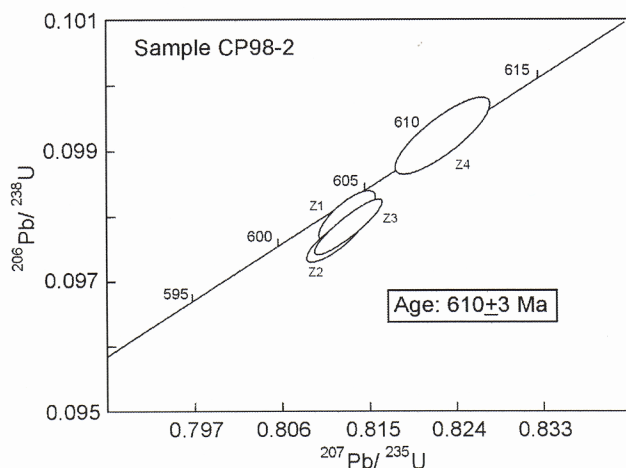


Figure 5. U-Pb concordia plot for granitoid sample from the Cape Porcupine Complex (Z1-Z4 refer to zircon populations; (Table 1).

represents the approximate age of all the granitoid rocks in the complex. Because the contacts are faulted, this age does not constrain the ages of the metasedimentary and metavolcanic units. However, the presence of volcanic xenoliths in the granitoid units suggests that the volcanic unit may be older.

Geochemistry

As a preliminary indication of the chemical character of the Cape Porcupine Complex, five granitic samples from the western granitoid unit (Fig. 3) were analyzed for major and selected trace elements by X-ray fluorescence at the Nova Scotia Regional Geochemical Centre, Saint Mary's University. The samples have SiO_2 contents greater than 74%, consistent with their felsic modal mineralogy and low mafic mineral content, and Zr/TiO_2 ratios like those of subalkaline rhyolite (Fig. 6a). On the Rb vs Y+Nb tectonic setting discrimination diagram, the samples plot in both the volcanic-arc and within-plate granite fields (Fig. 6b).

Additional chemical analyses are being done to investigate the petrogenesis of the granitoid units and their relationship to the metavolcanic rocks.

Structure and Metamorphism

Metasedimentary rocks in the Cape Porcupine Complex contain the mineral assemblage muscovite, chlorite, epidote and albitic plagioclase, indicative of lowermost greenschist facies metamorphism. The metasedimentary rocks display a well-developed mylonitic foliation defined by muscovite and chlorite that display uniform crystallographic orientation. The foliation strikes north-northwest with steep to shallow dips and near horizontal, north-south plunging stretching lineations (Fig. 7a). This deformation has also affected the metavolcanic rocks and some of the granitoid rocks in the eastern granitoid belt (Fig. 3). Preliminary observations suggest an overall dextral, strike-slip sense of movement. Bedding orientations in the Carboniferous sedimentary rocks are somewhat scattered but indicate upright, north-northeast plunging folds (Fig. 7b).

Much of the Cape Porcupine Complex has been overprinted by younger brittle deformation that resulted in numerous faults, breccia zones and the cataclastic textures observed in the granitoid units. Based on petrographic studies the main episode of alteration occurred during this brittle deformation. The lack of deformation and alteration in the clinopyroxene-bearing mafic dykes suggests that the alteration occurred before

Table 1. U-Pb analytical data.

Fraction ^a	Concentration		Measured		Corrected Atomic Ratios ^c						Age (Ma)			
	U (ppm)	Pb rad (ppm) ^b	Total Common Pb (pg)	$\frac{206\text{Pb}}{204\text{Pb}}$	$\frac{208\text{Pb}}{206\text{Pb}}$	$\frac{206\text{Pb}}{238\text{U}}$	$\frac{207\text{Pb}}{235\text{U}}$	$\frac{207\text{Pb}}{206\text{Pb}}$	$\frac{206\text{Pb}}{238\text{U}}$	$\frac{207\text{Pb}}{235\text{U}}$	$\frac{207\text{Pb}}{206\text{Pb}}$			
CP98-2														
Z1 sm clr 2:1 euh (42)	394	40.4	17	2525	0.1547	0.09801	32*	0.8127	24*	0.06014	12*	603	604	609
Z2 sm clr 2:1 euh (41)	482	48.8	26	1617	0.1467	0.09764	28*	0.8114	24*	0.06027	10*	601	603	613
Z3 sm clr 2:1 euh (37)	412	42.1	16	2883	0.1535	0.09784	34*	0.8128	28*	0.06026	10*	602	604	613
Z4 sm clr euh best (40)	324	33.3	15	1346	0.1440	0.09923	48*	0.8226	40*	0.06012	18*	610	610	608
^a All fractions were abraded following the method of Krogh (1982). Z, zircon; sm, small, euh, euhedral; clr, colourless; 2:1, length:breadth ratio. Number of analyzed grains in parentheses.														
^b Total radiogenic Pb after correction or blank, common Pb, and spike.														
^c Ratios corrected for fractionation, spike, 10-15 pg laboratory blank, initial common Pb (calculated with the model of Stacey and Kramers (1975) for the age of the sample), and 0.5 pg U blank.														
* Uncertainties (2 sigma) on the isotopic ratios refer to the final digits.														

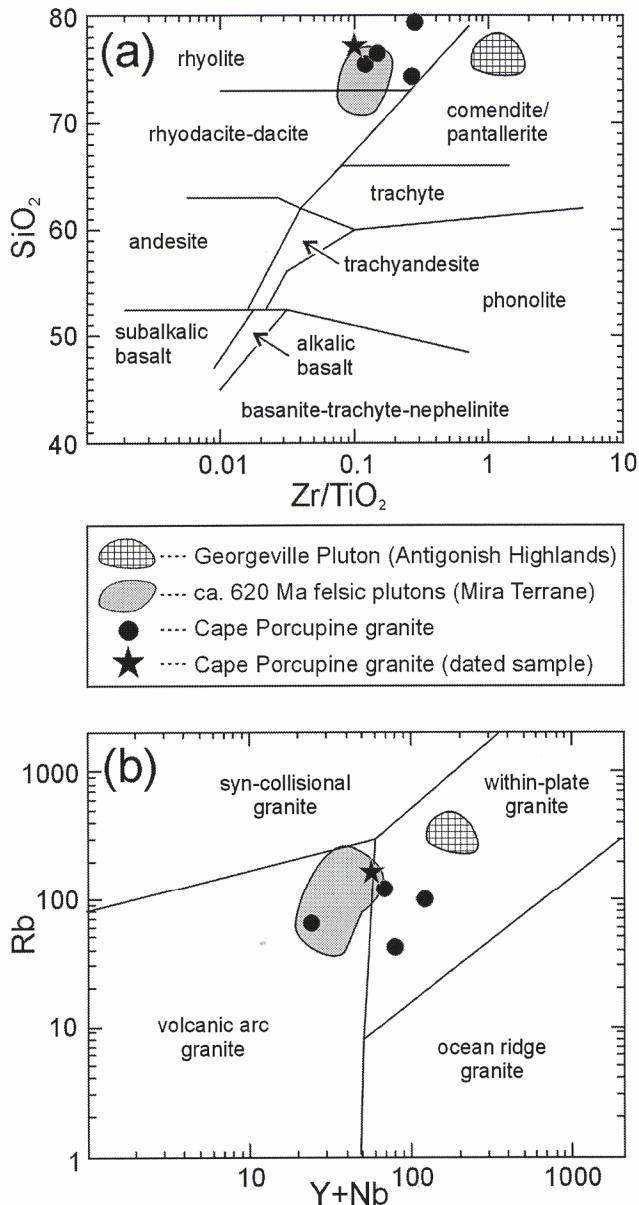


Figure 6. (a) Plot of Zr/TiO_2 against SiO_2 with fields from Winchester and Floyd (1977). (b) Tectonic setting discrimination diagram for felsic granitoid samples from the Cape Porcupine Complex. Granite fields from Pearce et al. (1984).

the early Carboniferous. However, the same clinopyroxene-bearing mafic dykes are locally offset by vertical and subhorizontal faults and breccia zones (e.g. Hilton, 1954; Rowley, 1956).

Economic Geology

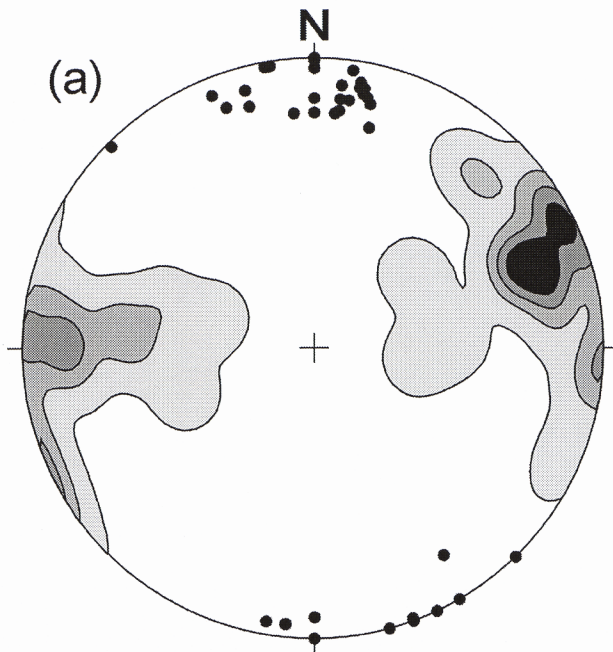
Quartz-carbonate veins are common in the complex and typically contain abundant pyrite, locally associated with sphalerite and chalcopyrite. In addition, abundant pyrite

with minor chalcopyrite also occurs as finely disseminated grains in granitoid and metavolcanic units. Minor malachite staining occurs along fractures in the metasedimentary unit. During quarrying operations in the 1950s, veins containing promising copper and gold leads were located but follow-up work showed them to be uneconomic (Hilton, 1954). Quartz veins containing gold were also reported to occur in the metasedimentary unit by Fletcher (1881), but were not confirmed during this study. Because of the intense alteration, low mafic mineral content, and abundant alkali feldspar, many of the granitoid rocks in the complex may have potential as a source of industrial feldspar used in glass and ceramic production. The granitic and metasedimentary rocks in the Cape Porcupine Complex are currently being exploited as a source of aggregate.

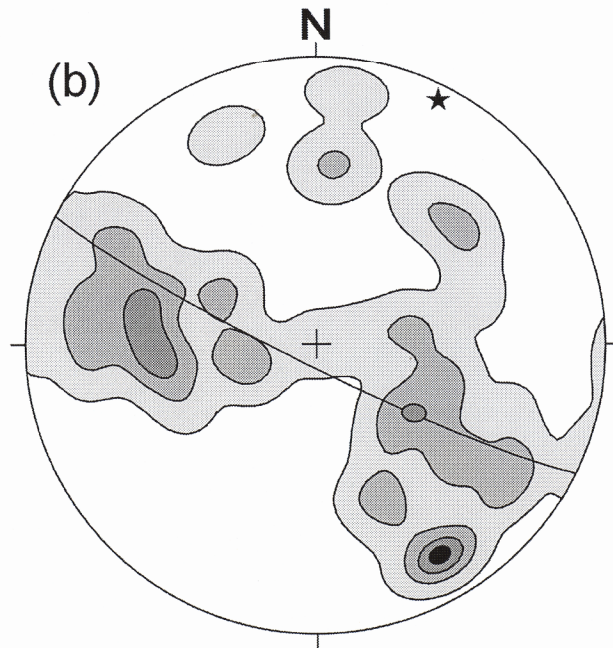
Regional Implications and Future Work

Based on the association of metasedimentary, metavolcanic and granitic rocks, Fletcher (1881, 1984), Ferguson (1946), Ferguson and Weeks (1950) and Keppie (2000) correlated the rocks at Cape Porcupine with the George River Group (Blues Brook Formation of Raeside and Barr, 1990) and associated granitic rocks exposed in the Creignish Hills in adjacent Cape Breton Island. However, in addition to clastic sedimentary and minor volcanic rocks, the Blues Brook Formation also includes marble and calc-silicate rocks that are not present in the Cape Porcupine Complex. Also, granitoid rocks in the Creignish Hills are not mineralogically or texturally similar to those in the Cape Porcupine Complex, and appear to be younger (White *et al.*, 1990; Keppie *et al.*, 2000).

Although correlation between the Cape Porcupine Complex and the Creignish Hills is supported somewhat by aeromagnetic data that suggest continuity between the two areas, the pattern is complex and disrupted by apparent NNW-trending structures (Fig. 8). The question of correlation is important for terrane interpretations (Fig. 2) because Barr and Raeside (1989) postulated the presence of a northwest-trending "Canso fault" under the Strait of Canso on the basis that geological units and terranes do not appear to correlate across the strait. The mylonitic rocks in the Cape Porcupine Complex may be the first direct evidence for the presence of the Canso fault.



Contoured poles to mylonitic foliation (n=37), contours at 1, 4, 7, and >10% per unit area, ● = stretching lineation (n=37)



Contoured poles to bedding in the Carboniferous units (n=55), contours at 1, 3, 5, and >7% per unit area, ★ = fold axis (026/06)

Figure 7. Summary of structural data from the Cape Porcupine area: (a) mylonitic fabrics; (b) Clam Harbour River Formation

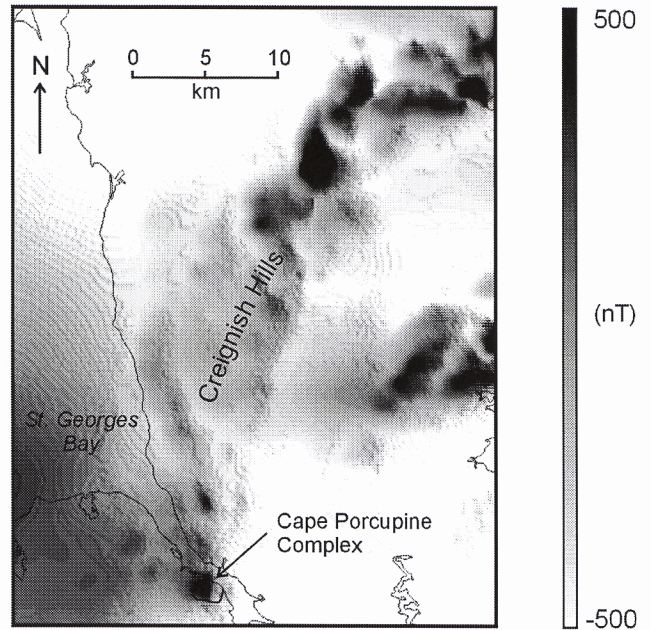


Figure 8. Grey-scale total magnetic field map of southwestern Cape Breton Island and the Strait of Canso area. Sun shading from the west at a 35° inclination. Data gridded at 100 m. Data from the Geological Survey of Canada (1997).

Units comparable in age and/or composition to those of the Cape Porcupine Complex also occur in the Mira terrane of southeastern Cape Breton Island, and in the Antigonish and Cobequid highlands of northern mainland Nova Scotia (Fig. 2). The ca. 610 Ma granite in the Cape Porcupine Complex is similar in age to some granitic units in the Mira terrane (Barr et al., 1996), and to the Georgeville Pluton in the Antigonish Highlands (Murphy et al., 1998). The analyzed samples from granite in the Cape Porcupine Complex appear similar to the more chemically evolved parts of the ca. 620 Ma calc-alkaline felsic plutons of the Mira terrane, but are chemically different from the alkalic rocks of the Georgeville Pluton (Fig. 6a, b). More detailed comparisons will be possible when a larger and more representative geochemical database has been obtained for granitoid and metavolcanic units in the Cape Porcupine Complex, and when the age of the metavolcanic unit is known.

At the present time, the relationship of the Cape Porcupine Complex to other igneous and metamorphic rocks in adjacent parts of Cape Breton Island and northern mainland Nova Scotia, and hence its terrane affiliation, remain uncertain.

Acknowledgments

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